

The following comparative readings were made under similar conditions, except the sun was covered 5<sup>m</sup> 30<sup>s</sup>.

Sept. 18.	Bright sunshine immediately preceding cloud.	Sun covered 5 <sup>m</sup> 30 <sup>s</sup> fell to —.	Amount of fall.	5 <sup>m</sup> 30 <sup>s</sup> of bright sunshine immediately following cloud.	Amount of rise.
	°F.	°F.	°F.	°F.	°F.
Soil.....	122.2	111.0	11.2	119.0	8.0
Sod.....	108.0	99.5	8.5	103.7	4.2
Sand.....	122.0	113.0	9.0	121.8	8.8
Shelter.....	90.0	88.2	1.8	90.3	2.1

Wind velocity, m. p. h., 2; direction, south.

Comparative readings in bright sunshine every 15 minutes, Sept. 16

	1:00 p. m.	1:15 p. m.	1:30 p. m.	1:45 p. m.	2:00 p. m.	2:15 p. m.	Average variability.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Soil.....	118.0	119.5	121.5	121.5	121.5	119.5	1.9
Sod.....	109.0	108.5	109.0	107.5	109.0	104.5	1.4
Sand.....	121.5	121.5	125.0	125.5	126.0	122.0	1.5
Shelter.....	89.0	89.0	89.5	91.0	91.0	91.0	.....

Wind velocity, m. p. h., 2; direction, southwest.

Comparative readings in bright sunshine every 5 minutes, Sept. 17 and 18.

Sept. 17.	2:15 p. m.	2:20 p. m.	2:25 p. m.	2:30 p. m.	2:35 p. m.	2:40 p. m.	Average variability.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Soil.....	119.5	119.0	119.5	120.8	107.0	104.2	3.1
Sod.....	104.5	104.2	105.0	106.0	104.0	101.0	1.2
Sand.....	122.0	121.0	121.9	124.8	121.0	118.0	1.9
Shelter.....	90.4	90.4	91.0	91.6	91.6	90.9	0.2

Wind velocity, m. p. h., 3; direction, southwest.

Sept. 18.	1:30 p. m.	1:35 p. m.	1:40 p. m.	1:45 p. m.	1:50 p. m.	1:55 p. m.	2:00 p. m.	Average variability.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Soil.....	118.0	114.0	116.6	119.7	119.0	117.0	121.0	2.2
Sod.....	105.0	102.0	103.9	106.0	106.0	104.0	106.5	1.6
Sand.....	118.0	113.3	117.0	119.0	118.8	116.2	120.0	2.4
Shelter.....	90.0	89.0	89.0	90.0	90.9	90.9	91.0	.....

Wind velocity, 2; direction, south.

<sup>1</sup> Movement of cooler shade temperature to thermometer beds.  
<sup>2</sup> Passing cumulus cloud.

## THE COOLING OF THE SOIL AT NIGHT, WITH SPECIAL REFERENCE TO LATE SPRING FROSTS.

By T. BEDFORD FRANKLIN.

[Abstracted from *Proceedings of the Royal Society of Edinburgh*, session 1919-20, Vol. XL, Pt. I, pp. 10-22.]

In a previous paper<sup>1</sup> Dr. Franklin came to the conclusion that the temperature of the surface of open cultivated soil fell rapidly at the beginning of a calm, clear night, until it was such a number of degrees below the temperature at the 4-inch depth as to make the upward conduction from that depth to the surface balance the radiation. After this stage was reached the surface and 4-inch temperatures fell at the same rate.

If, therefore, the temperatures of the surface and 4-inch depth and the conductivity of the layer of soil between the 4-inch depth and the surface were known from readings of electrical resistance thermometers, and the rate

of radiation was calculated from the value of the relative humidity, he suggested that it might be possible to forecast the minimum soil temperature for a calm, clear night as early as the previous afternoon.

In this second paper Dr. Franklin gives a formula for forecasting the minimum surface-soil temperature and compares this minimum with the air temperature immediately above.

He found that the conductivity of this surface layer of soil varied so greatly with different degrees of wetness that an average value could not be used. He therefore has adopted, instead, the ratio of the range of temperature at the 4-inch depth and at the surface, which he expresses by  $\frac{R_1}{R_0}$ .

The quantities required for the forecast equation are:

(1) The value of  $\frac{R_1}{R_0}$  from minimum to maximum, which can be obtained by about 5 or 6 o'clock p. m.

(2) The lag on the day in question; this may be observed by about 5 or 6 p. m., or may be found from the values of  $\frac{R_1}{R_0}$ .

(3) The estimated relative humidity of the coming night.

(4) The number of degrees ( $\theta$ ) which the surface can fall below the 4-inch temperature before the upward conduction balances the radiation; this depends on  $\frac{R_1}{R_0}$  and the relative humidity.

(5) The probable difference between the air minimum over open-soil and the surface-soil minimum.

1. Observations show that the ratio of  $\frac{R_1}{R_0}$  averages 0.42 immediately after a rain and 0.23 in dry soil. Intermediate results were found with varying amounts of soil moisture. These figures are for the particular soil and location where the records were taken. Dr. Franklin believes that only slight variations would be found at different places in the same type of soil. While he has not fully investigated the ratio in different soil types, he is of the opinion that the ratio will vary between 0.44 and 0.28 for loam, 0.60 and 0.41 for sand, and 0.41 and 0.35 for clay under similar weather conditions.

2. The lag between the 4-inch and the surface temperatures varies from 3½ hours when  $\frac{R_1}{R_0}$  equaled 0.44 to 5½ hours when the ratio was 0.20 and was fairly proportioned between these ratios.

3. The connection between  $\frac{R_1}{R_0}$ , the relative humidity, and the number of degrees centigrade ( $\theta$ ) which the surface can fall below the temperature of the 4-inch depth before the upward conduction balances the radiation is shown in the following table:

Values of  $\theta$  in °C.

Relative humidity.	Values of $\frac{R_1}{R_0}$							
	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44
90 per cent.....	8.0	7.5	7.0	6.5	6.0	5.5	5.0	4.6
80 per cent.....	8.7	8.1	7.6	7.0	6.5	6.0	5.5	5.0
70 per cent.....	9.5	8.9	8.3	7.7	7.1	6.6	6.1	5.5
60 per cent.....	10.2	9.6	9.0	8.4	7.8	7.2	6.6	6.1

<sup>1</sup> See review in MONTHLY WEATHER REVIEW, Dec., 1919, 47: 849.

4. On 10 nights when the surface of the ground was frozen the air temperature varied from  $3.2^{\circ}$  to  $0.3^{\circ}$  (C.) lower than the surface-soil temperature, with an average of  $2.7^{\circ}$  (C.) cooler. On 28 nights when the surface did not freeze the air temperature minimum averaged  $0.4^{\circ}$  (C.) higher than the surface-soil temperature, the variation being from  $1^{\circ}$  higher to  $1^{\circ}$  (C.) lower. It follows, therefore, that when the surface of the ground does not freeze the air minimum over open soil follows the surface-soil minimum very closely.

In a later paper in the same publication (pp. 56-79) Dr. Franklin discusses soil temperatures further under the head, "The Effect of Weather Changes on Soil Temperature." The following are brief quotations from this article:

In comparison with the variation of surface temperature, the regular pulsations of temperature underground follow well-known laws for amplitude and retardation according to depth; but in these regular pulsations there are minor fluctuations which occur either day by day or at irregular intervals, according to the weather and the state of the surface soil.

Of these minor fluctuations the most important are due to the percolation of rain, the movements of soil air and moisture, the presence of a dry surface mulch, the prevalence of strong winds of low relative humidity, or the occurrence of frost and snow. \* \* \*

Rain is a great equalizer of temperature between the surface and underground—in fact, it is probable that the first rise of temperature underground from the low level of winter is due to warm spring rains. \* \* \*

Snow is an extremely bad conductor, and as little as 4 inches of snow provides a complete protection for the surface from very large variation of temperature above the snow surface. \* \* \*

It is obvious that so long as the air temperature was above  $-15^{\circ}$  C. thawing must have been going on constantly at the bottom of the snow layer, this thawing being the more rapid the more the air temperature rose.

*The coming of spring.*—Spring, considered as the beginning of the period of active growth of crops, depends in the main on the soil temperature at the depth at which these crops grow. At first sight it would appear a simple matter—with the meteorological data for any year before us—to say whether that year had enjoyed an early or late spring; but when we study the phenological returns for the last 30 years the question assumes a more complex appearance.

If we plot the deviations from the normal of the date of first flowering of any plant against the corresponding deviations from normal for some chosen preceding period of the values of the mean, maximum, minimum, or soil temperatures, we do not find the closely corresponding results that we may have expected. As, however, mean values cover a multitude of variations, this is not to be wondered at, and it is doubtful if any good result can be obtained from monthly mean values at all. For let us consider two extreme months—

(1) With a very small range of temperature and a mean equal to the average.

(2) With a spell of frost for, say, 15 days, and very warm weather for 15 days, and a mean above the average.

Now, if the growing temperature for the plant considered was below the mean for the month, No. 1 would give nearly 30 growing days, and the plant would appear in flower earlier than in No. 2, which gives only 15 growing days, although the mean temperature of No. 2 is higher than of No. 1.

Thus not only the growing temperature of the plant, but the daily values that make up the mean, have to be known before we can make any rule for the behavior of the plant under the given conditions, and the date when the minimum soil temperature at from 4 to 6 inches depth passes the growing temperature of the proposed crop is the real question that concerns the cultivator.

If we take  $5.5^{\circ}$  C. as the average growing temperature of most crops, it is of interest to note how weather changes help forward or retard the arrival of this temperature in the soil at 4 inches depth.

In March and April, 1919, there was a succession of spells of very different weather, which showed by their influence on the 4-inch depth temperature that it is the overcast weather, with bright intervals and overcast nights, that most rapidly increases the temperature underground, and not, as might be expected, the bright, sunny weather with clear sky and low relative humidity.

These figures (omitted) emphasize the importance of the effect of frost and clear nights on underground temperatures: in fact, we may say that the soil temperature for any period in winter or spring is mainly dependent on the number of frosts which occur while the ground is open without deep-lying snow during that period. Frosts that occur when several inches of snow is lying have, as we have already seen,

little effect on soil temperature, owing to the great protection given by the snow. \* \* \*

*Conclusions.*—1. The values of  $\frac{R_4}{R_0}$  have a wide range of variation, from 0.19 in very dry soil to 0.85 during heavy rain; the most common value is about 0.40. The monthly mean values showed a decided connection between  $\frac{R_4}{R_0}$  and the frequency of rainfall; in fact, percolation of rain seems to be the dominating factor in deciding the value of  $\frac{R_4}{R_0}$ . This is also borne out by the different values of  $\frac{R_4}{R_0}$  in various soils according to their behavior with regard to water; in sand the values change with mercurial rapidity, due to the easy percolation of rain and subsequent rapid drying, while in clay they change but sluggishly, since clay takes up and parts with water with difficulty.

2. In view of the fact that the values of  $\frac{R_4}{R_0}$  and therefore the values of the diffusivity of the soil, are so dependent on the percolation of rain, it is possible that the values commonly given for the diffusivity of the surface layers of the earth need revision.

3. Underground temperatures are also considerably affected by—

(a) Strong winds of low relative humidity.

(b) The frequency and intensity of frost when the soil has no snow covering.

(c) The depth of snow.

(d) Weather changes of long period.

4. The date of flowering of Coltsfoot appears to bear little relation to the monthly mean values of temperature, but is closely related to the number of frosts on open soil not covered with deep snow. It is possible that good results would be obtained by comparing the phenological returns of the last thirty years with the accumulated temperature underground above the growing temperature for each plant considered.

—J. Warren Smith.

#### EFFECT OF SOIL ON FROST DAMAGE.

In a letter to *Science* (Mar. 28, 1919, pp. 310-311), Mr. T. G. Dabney describes the effect of the onslaught of a killing frost upon vegetation growing upon soils of different character. It was observed that cotton growing in the river silt near the old river bank of the Mississippi was not damaged, but that that growing back from the river bank in the heavy clay, known locally as "buckshot," was completely killed. The explanation offered was that the radiation from the silty soil during the cold night was sufficient to protect the plants, while the clay did not possess this property. The cold night was not preceded by other cold ones but came suddenly when the soil was warm. The country in the vicinity was very level.—C. L. M.

#### PREDICTING MINIMUM TEMPERATURES FROM THE PREVIOUS AFTERNOON WET-BULB TEMPERATURE.

In *Geografiska Annaler*, January, 1920 (pp. 20-32), Anders Ångström, of Upsala, Sweden, under the title "Studies of the Frost Problem, I," shows that very close minimum temperature forecasts can be made on comparatively clear nights by subtracting a constant from the wet-bulb temperature.

The constant was smallest and the percentage of accuracy highest when the observation of the wet-bulb temperature was made at about sunset, but fairly close predictions resulted from observation at other afternoon hours, even as early as 1 p. m. The constant varies with different hours and different months; Dr. Ångström found it to be greatest at 3 p. m.

The discussion shows "that the minimum temperature may be obtained through subtracting a constant value from the temperature of the wet bulb at sunset multi-